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Method for Pressure Modulation of Brake Pressures**Technical Field**

The present invention generally relates to vehicle brake systems, and more particularly relates to a method for the pressure modulation of brake pressures.

Background of The Invention

Beside a primary pressure fluid source for hydraulic fluid (e.g. the brake cylinder/tandem master cylinder), modern vehicle brake systems include one or a plurality of pressure fluid pumps which permit delivering hydraulic fluid that is (additionally) pressurized for defined purposes. For example, these pumps are pressure fluid pumps which are arranged on the valve block and can be operated by way of electric actuation of an electric motor and an eccentric. The purpose of these pressure fluid pumps is the active pressure build-up for defined controlling or regulating purposes when the brake pressure that originates from the main pressure source is not sufficient to reach the control objective. Traction slip control can be named as an example. In the presence of traction slip, the driver generally does not brake at all so that the primary pressure source does not furnish pressure. However, to control traction slip, an active introduction, maintaining, or reduction of brake pressure, in particular on the brakes of the driven wheels, may be desirable so that a device for pressure modulation including pressure build-up must be provided. This device may include the pressure fluid pump mentioned hereinabove.

In a method for pressure modulation of brake pressures for a dual-circuit brake system e.g. with a front-axle/rear-axle split-up on one-axle drive vehicles or with any desired brake force split-up in all-wheel drive vehicles, that is in all dual-circuit brake pressure transmission devices where an active pressure modulation in both wheels with a different brake pressure demand in both wheel brake circuits is provided, this brake pressure modulation has so far

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been performed by separately actuating inlet and outlet valves of the respective wheel brake circuit for controlling the traction slip. The pressure fluid source is separated from the pressure-side delivery circuit of the pressure fluid pump to prevent the hydraulic fluid from returning into the pressure fluid source. The above separation is effected by means of a separating valve.

The delivery rate and, thus, indirectly the brake pressure is adjusted this way in each of the two wheel brake circuits of a brake pressure transmission device. However, this suffers from the disadvantage that the valves operate against the pressure of the pressure fluid pump. This produces noises which is audible to the driver and may leave the impression that there is something wrong with the vehicle.

In addition, the prior art pressure modulation by way of the separate actuation of inlet and outlet valves provides a discharge of the brake pressure from both wheel brake circuits via the outlet valves. The pressure fluid flows through the pressure fluid pump and the pressure-limiting valve associated with the separating valve and predefining the pressure level of the brake pressure transmission circuit back into the pressure fluid source. Especially in driving stability control operations and with rear-axle driven vehicles with a high pressure level of the brake pressure transmission circuit, the pressure fluid pump is loaded to a considerable degree because it operates against a high pressure. In addition, noise which is also audible to the driver is produced during overflow of the pressure-limiting valve and during supply by the pressure fluid pump.

A brake system of this type is described in DE 44 27 247 A1. This brake system permits performing a controlled pedal force braking operation and a controlled braking operation by independent force. Pedal force braking refers to a braking operation wherein a brake pressure predetermined by the brake pressure transmission device is built up in the wheel brake circuit by an actuation of the brake cylinder which is intended by the driver, while in a braking operation by independent force, irrespective of pedal application, brake pressure is built up in the wheel brake circuits which can be modulated according to defined control algorithms,

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such as in traction slip control or driving stability control operations. In a traction slip control operation, the brake pressure in the brakes of the driven wheels is adjusted so that the engine torque reduced by the brake torque can be transmitted from the tires to the roadway without spinning of the wheels.

The known brake pressure transmission device is comprised of the inlet and outlet valves, the switch valve, the separating valve, the low-pressure accumulators and a return pump. By operation of the inlet and outlet valves, the pressure is introduced, maintained, and reduced in the connected wheel brakes during braking by independent force. The pressure is built up in both wheel brake circuits when the inlet and switch valves are opened and the separating and outlet valves closed. When the pressure of the brake pressure demand is reached, the two inlet valves will be closed, while the return pump is still active. A sufficiently high pressure is built up by the return pump on the inlet side ahead of the inlet valves which prevents a discharge of the pressure fluid by way of the non-return valves bypassing the inlet valve. The switch valve is closed thereafter. Pressure is maintained with the valves closed so that no hydraulic pressure fluid can flow in the wheel brake circuits via switch valve, separating valve, and inlet and outlet valves. For pressure reduction, the outlet valves are opened according to one variation of embodiment so that the pressurized pressure fluid prevailing in the wheel brakes discharges into the low-pressure accumulators from where it is conveyed to the brake cylinder by means of the return pump. The purpose of the low-pressure generator generally is to intermediately store the pressure fluid which is discharged from the wheel brake circuits in the event of a quick pressure reduction, because the return pump, due to its limited conveying capacity, may only supply a defined quantity of pressure fluid per time unit. In another design variation, the inlet valve and the separating valve of a wheel brake circuit are opened so that the pressure fluid of the respective wheel brake circuit flows off through the opened inlet valve directly to the brake cylinder and through said to the pressure fluid source.

 An object of the present invention is to provide a method for the pressure modulation of brake pressures which reduces noise emissions and enhances the possibility of braking intervention during braking by independent force.

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The method of pressure modulation of brake pressures with an electric pressure fluid pump in a dual-circuit brake pressure transmission device, with the steps introduction of a brake pressure into the one and/or the other wheel brake circuit of the one brake pressure transmission circuit, maintaining the brake pressure in the one and/or the other wheel brake circuit of the one brake pressure transmission circuit, and discharge of the brake pressure into the one and/or the other wheel brake circuit of the one brake pressure transmission circuit, wherein a split-up of the wheel brake circuits of the one brake pressure transmission circuit into a leading and a following wheel brake circuit with different brake pressure demands is provided, and wherein the leading wheel brake circuit is defined as wheel brake circuit with a higher brake pressure demand, and wherein further the steps introduction, maintaining, and reduction of the brake pressures of the following wheel brake circuit are controlled or regulated by way of the leading wheel brake circuit, the noise emissions in braking by independent force are reduced because the inlet valve of the leading wheel brake circuit remains open also after the brake pressure demand has been reached so that this valve is not required to operate in opposition to the pressure of the pressure fluid pump. Admittedly, the closed inlet valve of the following wheel brake circuit operates in opposition to the pressure of the pressure fluid pump, however, this pressure in the following wheel brake circuit is limited to the differential pressure between the leading and following wheel brake circuit so that the noise emissions during opening of this inlet valve are also reduced. The open inlet valve permits a pedal force braking operation also during pressure modulation.

In an embodiment of the present invention, the wheel brake circuit of the leading wheel is connected to a pressure fluid source (supply reservoir, brake cylinder) by way of opening of a switch valve, and the pressure fluid is introduced into the leading and following wheel brake circuits by way of the pressure fluid pump arranged in the wheel brake circuit, with the brake pressure circuit being separated from the pressure fluid source by a separating valve. This action renders it possible with normally open inlet valves to build up the pressure in both wheel brake circuits corresponding to a brake pressure demand of the wheel brake circuits.

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In another embodiment of the present invention, the wheel brake circuit of the leading wheel is connected to a pressure fluid accumulator, with a switch valve closed, and the pressure fluid is introduced into the leading and following wheel brake circuit by way of the pressure fluid pump arranged in the wheel brake circuit, with a brake pressure circuit being separated from a pressure fluid source by a separating valve. Depending on the charging condition of the pressure accumulator (low-pressure accumulator) the pressure fluid required for the pressure build-up for the two wheel brake circuits can be taken from this pressure fluid accumulator and/or the pressure fluid source.

According to the present invention, one inlet valve and one outlet valve is provided in each wheel brake circuit, and the brake pressure demand of the leading and following wheel brake circuits is controlled by way of the inlet valve of the following wheel brake circuit and the pressure fluid supplied by the pressure fluid pump according to the brake pressure demand, with the inlet valve of the leading wheel brake circuit being open, and the outlet valves of the leading and following wheel brake circuit being closed. Due to the division into a leading wheel brake circuit with a higher pressure demand and a following wheel brake circuit with a lower pressure demand, the brake pressure demand of the following wheel brake circuit can always be built up from the leading wheel brake circuit. In this arrangement, the pressure fluid pump for the brake pressure adjustment furnishes only the delivery rate necessary to satisfy the brake pressure demand of the leading wheel brake circuit, there being no need to actuate the inlet valve of the leading wheel brake circuit which is open in its deenergized state.

When the pressure of the following wheel brake circuit must be corrected because e.g. the coefficient of friction of the ground changes during traction slip control, the brake pressure demand of the following wheel brake circuit is changed from the leading wheel brake circuit by opening the inlet valve of the following wheel brake circuit, with the pressure fluid pump being active or passive. When only minor pressure variations must be effected in the following wheel brake circuit, the pressure in the following wheel brake circuit can be changed exclusively out of the leading wheel brake circuit, in the event of a sufficient

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difference in pressure between the leading and following wheel brake circuits, without the requirement to correct the pressure in the leading wheel brake circuit towards the brake pressure demand. Advantageously, the brake pressure of the wheel brake circuits is maintained, with the switch valve, separating valve and outlet valve closed, the inlet valve of the leading wheel brake circuit open, and the outlet and inlet valve of the following wheel brake circuit closed. Pedal force braking is possible in this mode of braking by independent force due to the inlet valve of the leading wheel brake circuit being open.

In another variant (special case), the inlet valve of the leading wheel brake circuit is closed in dependence on the brake pressure in the wheel brake circuit or in dependence on a time constant correlated to a condition variable. The inlet valve is closed after a predetermined time after closing of the switch valve. The volume prevailing in the pressure fluid accumulator is then returned into the brake cylinder and the supply reservoir by way of a pressure-limiting valve bypassing the separating valve. This variation is e.g. used only when volume exists in the pressure fluid accumulator due to pressure reduction in the following wheel brake circuit, and in driving situations, such as for example a traction slip control operation at a homogeneous coefficient, in which exceeding of the pressure above the value of the brake pressure demand has considerable negative effects on the wheel behavior.

When, in another embodiment of the present invention, the brake pressure introduced is increased compared to the brake pressure demand, the brake pressure according to a first variation is discharged by way of the brake pressure circuit into the pressure fluid source by opening the separating valve in the leading wheel brake circuit, with the switch and outlet valve closed and the inlet valve open. In a second variation, the brake pressure in the following wheel brake circuit is discharged through a return line into the pressure fluid accumulator by opening the outlet valve when the inlet valve is closed, with the switch valve and/or separating valve in the leading wheel brake circuit being closed or opened in dependence on the steps introduction, or maintaining, or reduction of the brake pressure.

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The controlling or regulating signals for the actuation of the valves according to the method of the present invention, which signals are based on calculated characteristics for the steps introduction, maintaining, and reduction, are predetermined by a pressure controller in which a pressure model is stored and which is connected to the controlling or regulating units for an anti-lock function and/or traction slip control and/or a driving stability function.

For the brake pressure adjustment in the leading and following wheel brake circuits, the pressure fluid pump is controlled by way of gradual quantities predetermined by the pressure controller so that the pump is operated gradually. Operating conditions/delivery rates/rotational speeds of the pressure fluid pump are adjusted by way of the calculated brake pressure demands by way of the electric actuation, for example, by way of a pulse-width modulated signal so that the pressure fluid pump itself is a control element for the adjustment of the brake pressure.

A change in the initial condition of the pump piston, as it occurs upon deactivation of the pressure fluid pump, is avoided because the pressure fluid pump is operated during the steps maintaining and reduction by way of adjusting the energy supply, and/or the rotational speed, and/or the conveying capacity in a predetermined basic (load) condition, preferably with a lowest energy supply, rotational speed, and/or conveying capacity, that means that the pressure fluid pump is actuated so that it will not come to a standstill. This reliably prevents that a delivery volume that is responsive to the pump piston position will lead to an undefined brake pressure adjustment in the wheel brake circuits upon each activation of the pressure fluid pump.

It is, of course, also possible to switch off the return pump when the influence of the delivery volume which is changed due to the pump piston position can be left out of account in the instance the return pump starts to operate.

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Brief Description of The Drawings

Figure 1 is a view of the hydraulic circuit diagram of a brake system according to the present invention.

Figure 2 is a wiring scheme relating to the actuation of the valves, comprising the steps introduction, maintaining, and reduction.

Detailed Description of The Preferred Embodiments

The dual-circuit brake pressure transmission device for vehicles, as illustrated in Figure 1, is comprised of a brake cylinder 1 with a brake force booster 2 which is operated by a brake pedal 3. A supply reservoir 4 is arranged at the brake cylinder 1 which contains a pressure fluid volume and is connected to the working chamber of the brake cylinder 1 in the brake release position. The one brake pressure transmission circuit illustrated includes a brake line 5 that is connected to a working chamber of the brake cylinder 1 and has a separating valve 6 which, in its inactive position, provides an open passage for the brake line 5. The separating valve 6 is usually operated electromagnetically. However, variations where a hydraulic actuation is carried out are also feasible.

The brake line 5 branches into two brake pressure lines 8, 9 which lead to a wheel brake 10, 11, respectively. Each of the brake pressure lines 8, 9 contains an electromagnetically operable inlet valve 12, 19 which is open in its inactive position and can be switched to assume a closed position by energization of the actuating magnet. Connected in parallel to each inlet valve 12, 19 is a non-return valve 13 which opens in the direction of the brake cylinder 1. Connected in parallel to these wheel brake circuits 26, 27 is a so-called return delivery circuit which comprises return lines 15, 32, 33 with a return pump 16. By way of one outlet valve 14, 17, respectively, and return lines 32, 33, the wheel brakes 10, 11 are connected to the return line 15 and, hence, to the suction side of the return pump 16 whose

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pressure side is connected to the brake pressure line 8 in an opening point E between the separating valve 6 and the inlet valves 12, 19.

The return pump 16 is designed as a stroke piston pump with a pressure valve (not shown) and a suction valve. At the suction side of the return pump 16, there is a low-pressure accumulator 20 consisting of a housing 21 with a spring 22 and a piston 23.

A biassed non-return valve 34 which opens towards the return pump is inserted into the connection between the low-pressure accumulator 20 and the return pump.

Further, the suction side of the return pump 16 is connected to the brake cylinder 1 by way of an additional line 30 with a low-pressure damper 18 and a switch valve 31. Additionally, the brake force transmission circuit includes a pressure controller 28 with a pressure model 29 for calculating the brake pressure demands in the wheel brake circuits 26, 27. In the pressure controller or in other electronic control units, the wheel brake circuits 26, 27 are evaluated according to the magnitude of the brake pressure demands on the basis of the calculated brake pressure demands in each of the wheel circuits 26, 27. The wheel brake circuits 26 or 27 are divided into a leading and a following wheel brake circuit, respectively, such that the wheel brake circuit, e.g. 26, with the higher brake pressure demand is determined as the leading wheel brake circuit and that the circuit with the lower brake pressure demand is determined as the following wheel brake circuit 27.

In dependence on the steps introduction, maintaining, or reduction of the brake pressures in the wheel brake circuits 26, 27 in a traction slip control operation, controlling or regulating quantities which permit actuating the valves 12, 19, 6, 17, 31 and the return pump are generated based on the brake pressure demands in the pressure controller 28. The following wheel brake circuit 27, is controlled or regulated by way of the leading wheel brake circuit 26. Specifically, hydraulic pressure fluid is introduced upon pressure build-up into the following wheel brake circuit with the lower brake pressure demand in the magnitude of the brake pressure demand from or by way of the leading wheel brake circuit.

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As is shown in Figure 2, the pressure build-up in the wheel brake circuits 26, 27 takes place when the switch valve 31 is open and the separating valve 6 closed by way of the actuating signals A and B, with the separating valve 6 being normally open in the initial position and the switch valve 31 being normally closed. In this arrangement, the return pump 16 arranges for the supply of pressure fluid out of the supply reservoir 4 or the low-pressure accumulator 20, by way of the brake cylinder 1, into the wheel brake circuits 26, 27 in which pressure fluid is so introduced in conformity with the calculated brake pressure demand. The pressure fluid is conducted to the wheel brakes 10 and 11 via the opening point E from the brake pressure line 8 of the leading wheel brake circuit 26 and into the brake pressure line 9 of the following wheel brake circuit 27 by way of the inlet valves 12 and 19, respectively. When the calculated value of the brake pressure demand in the following wheel brake circuit 27 is adjusted, the inlet valve 19 is closed by means of a switching pulse. The pressure fluid is introduced by the gradually actuated motor of the return pump in the leading wheel brake circuit 26 until the brake pressure demand is reached. Subsequently, the inlet valve 12 remains open, and the switch valve 31 will be closed. Separating valve 6 remains closed. A constant pressure C develops.

The brake pressure in the wheel brake circuits 26, 27 is maintained preferably when the inlet valve 12 is open. The return pump 16 is operated in a basic load condition, that means with lowest conveying capacity, and/or energy supply, and/or rotational speed so that the pump piston is just about moved by the eccentric. This operation of the return pump 16 in the basic load condition is preferably controlled by way of the pulse-width modulated actuation of the pump motor when no pressure fluid volume is stored in the low-pressure accumulator 20. In a special case which is not desirable, an excess pressure that is due to the replenishment supply of the return pump out of the low-pressure accumulator 20 or damper 18 during maintaining the brake pressure in the leading wheel brake circuit 26 is effectively prevented by closing of the inlet valve 12. Closing of the inlet valve 12 is effected by a time-responsive switching pulse after closing of the switch valve 31 in driving situations, such as a traction slip control operation on a homogeneous coefficient of friction, in which exceeding of the pressure

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beyond the value of the brake pressure demand has considerable negative effects on the wheel behavior. Alternatively, the brake pressure as well can be sensed or calculated, and the inlet valve 12 can be closed in response to the brake pressure. The contents of the low-pressure accumulator 20 and/or damper 18 is returned into the brake cylinder 1 and the supply reservoir 4 by way of the pressure-relief valve 25.

The pressure discharge F of the leading wheel brake circuit 26 is effected by opening the separating valve 6 so that pressure fluid flows through the open inlet valve 12, the separating valve 6, and the brake cylinder 1 into the supply reservoir 4. The separating valve 6 is closed by the pressure controller 28 by means of switching pulses D after each pressure reduction. In the following wheel brake circuit 27, pressure fluid is returned out of the wheel brake 11 into the low-pressure accumulator 20 when the outlet valve 17 is open and the inlet valve 19 closed. The low-pressure accumulator 20 assumes a buffer function in this operation.

A correction of the brake pressure demand of the following wheel brake circuit 27 towards a brake pressure increase is carried out by opening the inlet valve 19 out of the leading wheel brake circuit whose brake pressure demand is also corrected in dependence on predetermined control thresholds or wherein the reduced brake pressure is tolerated.